Modeling and Control of Air Supply in Multi-Stack Fuel Cell Systems for Aircraft Application

Markus Schorr[1*], Jannik Holtorf[1], Christoph Gentner[1]
[1]German Aerospace Center (DLR), Institute of Engineering Thermodynamics, Hamburg, Germany
[*]markus.schorr@dlr.de

Motivation

Electrification of aircraft propulsion using fuel cells will likely rely on **Multi-Stack Fuel Cell Systems** (MFCS) to meet the required power demand[1]. Major control challenges arise with the **dynamic operation** of MFCS which needs to be overcome in order to achieve the **certification requirements** and desired **stack lifetime**. For that purpose the Institute of Engineering Thermodynamics at DLR has developed and built a demonstrator of a MFCS in order to **analyze transient system behavior** and **investigate suitable control algorithms** relying on model based methods. Exemplarily, this procedure is shown by the example of an air supply controller.

Lab Scale MFCS Demonstrator

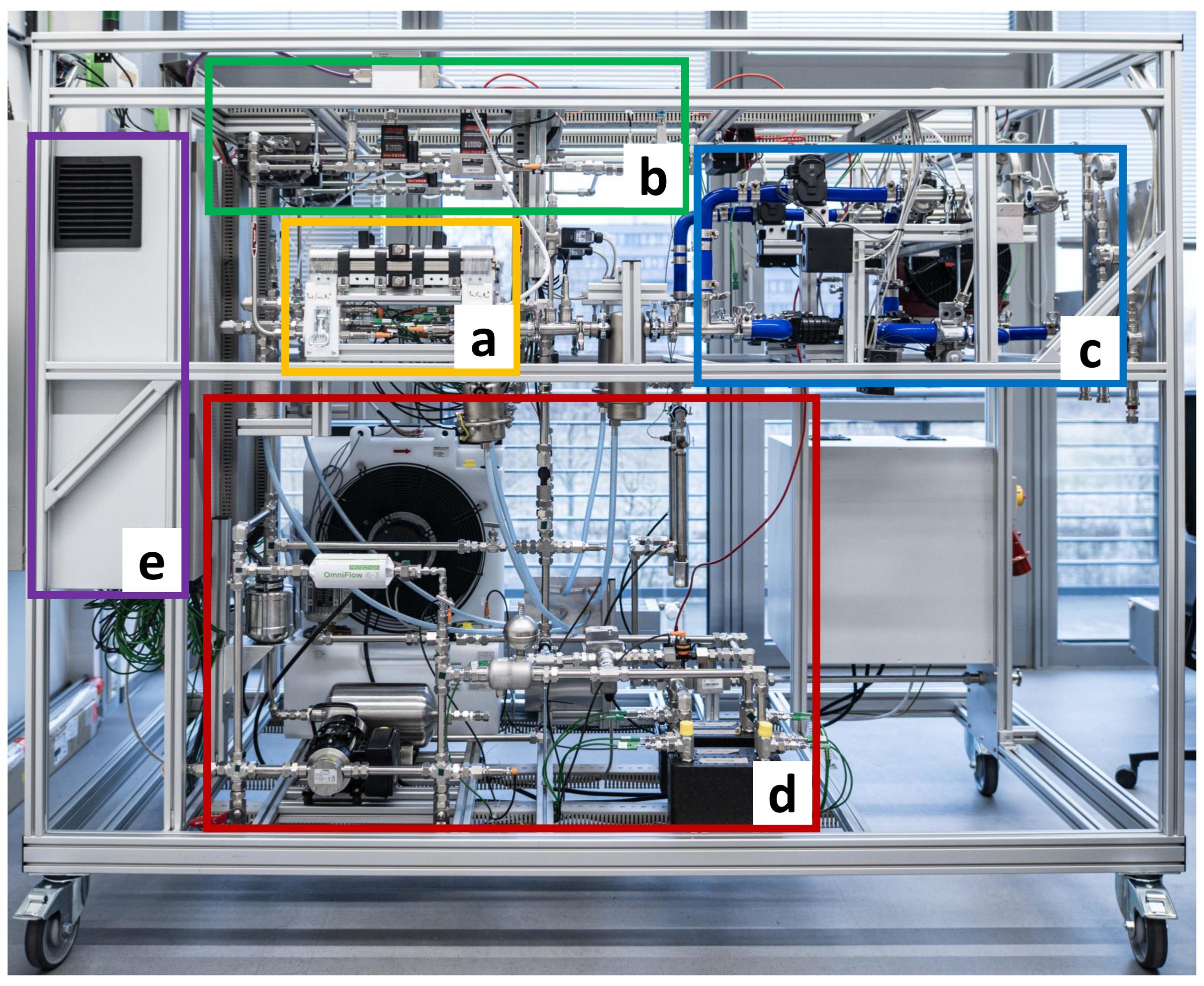

Figure 1: MFCS demonstrator with (a) two PEMFC Stacks, (b) hydrogen supply, (c) air supply, (d) cooling circuit and (e) PLC & power supply.

DLR has engineered and build a demonstrator to study dynamic behavior and validate control algorithms.

- 2 x 6kW PEM fuel cell stacks
- Shared balance of plant components to meet a high level of integration
- Designed to meet aviation requirements, e.g. pressurized cooling circuit
- Bachmann programmable logic controller (PLC) with Matlab/Simulink® interface

Air Supply Control Design

- Air supply line (*Fig. 2*) actuators are one mass flow controller (MFC) and two throttle valves (TV) to regulate airflow distribution.
- Control objective: Stack feed pressure p_2 and mass flow $\dot{m}_A$ and $\dot{m}_B$ through stacks.

Modelling approach

- All components are lumped into three volume elements with capacity C and Resistance R with laminar and turbulent contribution[2]:

$$R = \frac{p_0}{p_{in}}(R_{lam} + K_{turb}\dot{m}).$$

- Resulting differential state equations:

$$\frac{d}{dt}\dot{m}_1 = \frac{1}{\tau_{MFC}}(\dot{m}_d - \dot{m}_1)$$

$$\frac{d}{dt}p_1 = \frac{1}{C_1}\left(\dot{m}_1 - \frac{p_1 - p_2}{R_1}\right)$$

$$\frac{d}{dt}p_2 = \frac{1}{C_2}\left(\dot{m}_2 - \frac{p_2 - p_{amb}}{R_{2A} + R_{TVA}} - \frac{p_2 - p_{amb}}{R_{2B} + R_{TVB}}\right)$$

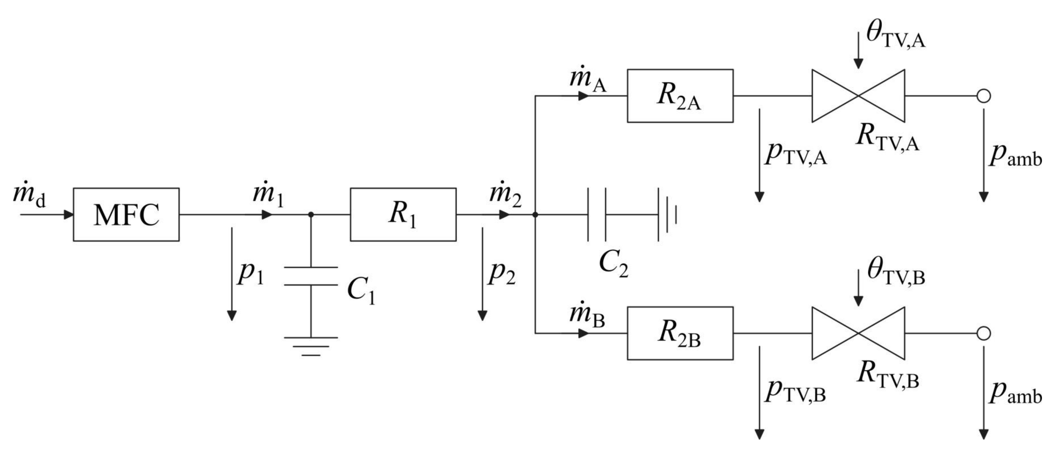

Figure 2: Equivalent circuit model of air supply line

- MFC is modeled as a first order system.
- Throttle valve position θ is assumed as a first order system, the flow resistance is a fitted function of position and mass flow.

$$R_{TV} = f(\dot{m}, \theta), \text{with} \quad \tau_{TV}\dot{\theta} = \theta_d - \theta$$

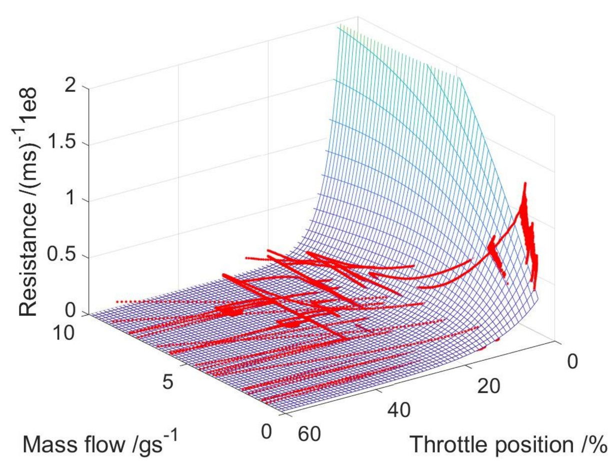

Figure 3: Surface fit of the throttle valve resistance as a function of mass flow and throttle position

- System parameters have been identified from dedicated measurements of the MFCS demonstrator via optimization.

Control design

- Nonlinear system is linearized around an intermediate operating point.
- A State feedback with state correction[3] and an integral error feedback is applied to achieve command tracking.
- Gain matrix K has been tuned using optimal control law (LQR).

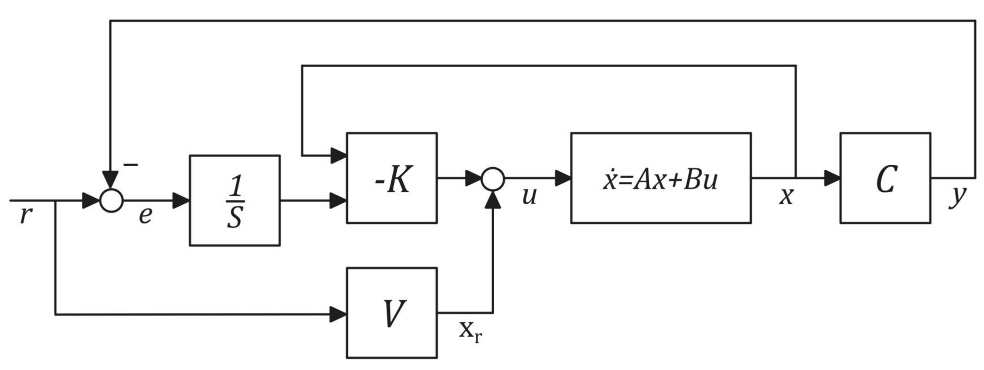

Figure 4: Structure of the feedback controller

Results & Discussion

- Modell shows satisfying agreement with measured outputs from the demonstrator.
- Reference can be tracked well and disturbance rejection shows fast recovery.
- Maximum MFC output limits the risetime on p_2.
- Nonlinearities are significant and controller could be adapted for a wider operating range.

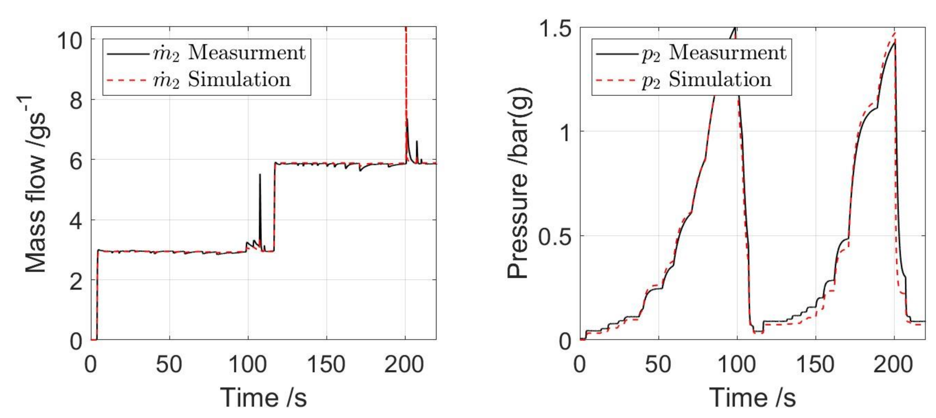

Figure 5: Comparison of simulated and measured response

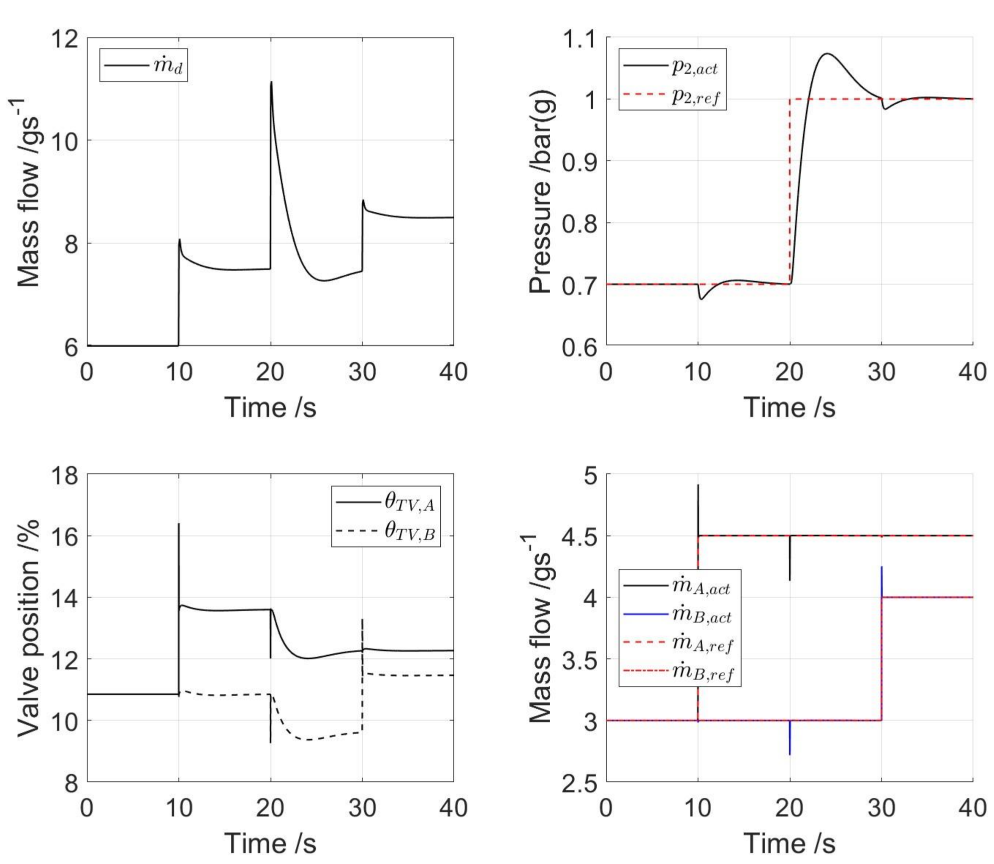

Figure 6: Response of controlled air supply system from the nonlinear model

Summary & Outlook

- A suitable plant representation of the air supply has been established and an efficient control strategy has been applied.
- The controller will be further refined and validated through demonstrator tests.
- All other control loops of the remaining MFCS subsystems will be investigated.

References

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